TITLE
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Milliarcsecond structure of methanol masers in L1206 and GL2789

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Abstract. We report results of EVN interferometric study of two star-forming regions L1206 and GL2789 in the brightest methanol maser line at 6.7 GHz. Using measured absolute positions both methanol masers were identified with protostars which are sources of bipolar outflows. Both masers consist of several maser spots, with some of them being aligned in a linear structure with velocity gradient probably delineating edge-on circumstellar disks. We estimated the radii of such disks to be 140 AU and 280 AU (or 700 AU for the whole structure treated as a disk) for L1206 and GL2789 respectively. The brightness temperatures of the most intense features in L1206 and GL2789 are at least 1.1×10^{10} K and 1.4×10^{9}K respectively.

1. Introduction

The $5_1 - 6_0$ A$^+$ methanol transition at 6.7 GHz produces the brightest known methanol masers. Many recent interferometric studies of such masers reveal geometrically ordered structures formed by maser spots sometimes with velocity gradients (Norris et al. 1993; Phillips et al. 1998; Minier et al. 2001). Such linear structures can be explained in the model of the rotating Keplerian disk seen edge-on. In this paper we present results of EVN observations of two methanol masers L1206 and GL2789, which were previously detected in Medicina survey (Slysh et al. 1999). These masers are not associated with ultra-compact H II regions, in contrast to the majority of strong masers.

2. Results

The correlated spectra of L1206 and GL2789 on the short baseline Effelsberg − Medicina are shown in Fig. 1. There are 2 and 4 features for L1206 and GL2789 spectrum respectively, maser spots corresponding to each spectral feature are shown in the component map in Fig. 2. The most intense L1206 feature A at -11 km s^{-1} and GL2789 feature B at -42.5 km s^{-1} were taken as reference features during self-calibration. The absolute positions of these features were determined using the fringe rate method yielding $\alpha = 22^h28^m51\overset{s}{.}44 \pm 0\overset{s}{.}02$, $\delta = 64^\circ13'41\overset{''}{.}31 \pm 0\overset{''}{.}1$ (J2000.0) for L1206 feature A and $\alpha = 21^h39^m58\overset{s}{.}29 \pm 0\overset{s}{.}01$, $\delta = 50^\circ14'21\overset{''}{.}0 \pm 0\overset{''}{.}1$ (J2000.0) for GL2789 feature B. Such positions allow us to identify both masers with protostellar sources seen in the infrared, with the maser in GL2789 being projected directly onto the center of spherical object

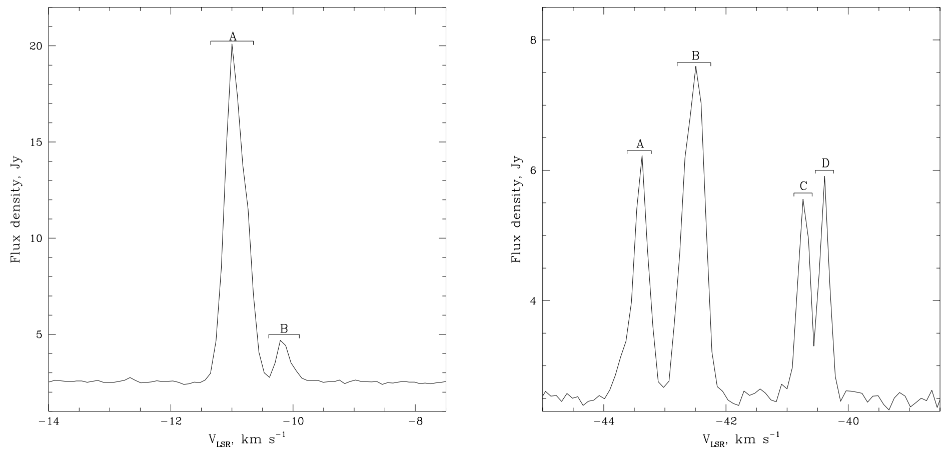

Figure 1. The correlated spectra on the Effelsberg − Medicina baseline for methanol masers in L1206 (left) and GL2789 (right).

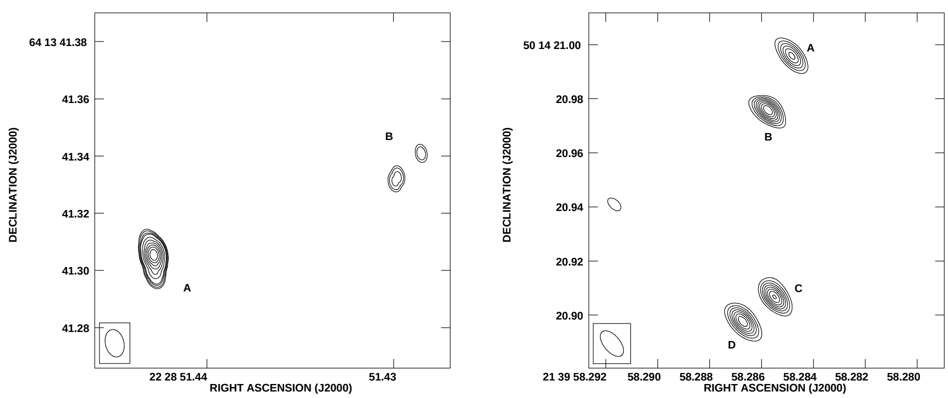

Figure 2. The component map of the masers. Left is L1206, contours are 0.6×(1, 1.5, 2, 2.3, 3, 4, 5, 6, 7, 8, 9) Jy/beam. Right is GL2789, contours are 0.22×(2,3,4,5,6,7,8,9) Jy/beam. All spectral channels are summed together.

N0 (Ressler & Shure 1991; Minchin et al. 1991). The sizes of feature A in L1206 and feature B in GL2789 have been measured to be less than 5.4 mas and 6.5 mas, implying brightness temperatures more than 1.1×10^{10} K and 1.4×10^{9} K, respectively. These high values can be explained by the current maser models by Sobolev et al. (1997).

3. Discussion

3.1. L1206

The maser consists of two maser spots separated by about 200 mas, or 200 AU at the distance of 1 kpc. The most intense feature A in L1206 has, in turn,

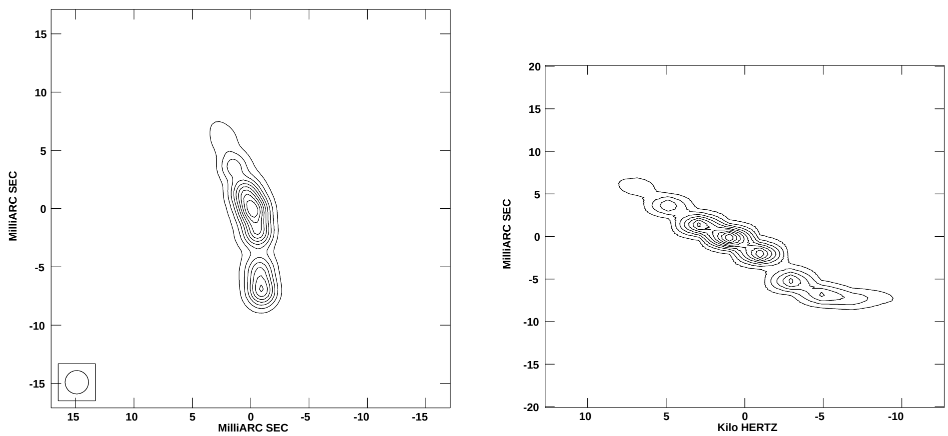

Figure 3. Left: a super-resolution image of the L1206 feature A, all spectral channels are averaged together. Contours are 0.13×(1, 2, 3, 4, 5, 6, 7, 8, 9) Jy/beam. Right: declination – frequency diagram for the left image. Contours are 0.43×(1, 2, 3, 4, 5, 6, 7, 8, 9) Jy/beam.

its own structure: individual spectral channels inside the line profile produce unresolved images with our resolution, but images corresponding to different spectral channels have slightly different positions. To investigate this structure the feature A was imaged using the super-resolution technique with the circular 2 mas restoring beam, as compared to the synthesized beam of 9.7×6.5 mas for L1206 and 11.3×5.6 mas for GL2789. The result of this mapping shown in the left side of Fig. 3 is a structure which is very close to the line in the south-north direction. There is a linear velocity gradient along this structure shown at declination – frequency diagram in the right side of Fig. 3. The least square fit to the diagram gives a slope $\Delta V_{km\ s^{-1}}/\Delta\delta_{mas} = -(0.040\pm0.006)$ km s^{-1} mas^{-1}. Assuming that maser spots delineate a disk with Keplerian velocity field, one can estimate the ratio M/R^3 for such disk, where M is the star mass and R is the disk radius. Note, that this ratio can be determined with considerably higher accuracy than the mass or the radius alone. Assuming that the disk is not inclined and the distance to the source is 1 kpc, one obtains $M/R^3 = (1.8\pm0.3)\times10^{-6}$ M$_\odot$AU^{-3}. This value is an order of magnitude higher than that obtained by Minier et al. (2001) for other sources. The disk radius delineating by the small scale structure of the feature A in L1206 is about 140 AU, if we assume that the central object has a mass of 5 M$_\odot$ as follows from its infrared luminosity (Ressler & Shure 1991). The part of this disk traced by methanol masers (the total size of the spot A) is only 15 AU in extent. Linear distance between features A and B is comparable to the estimated disk size. However, the direction from the feature A to the feature B is not coincident with the direction traced by the disk and is close to the direction perpendicular to the disk plane. Also, this direction is close to the direction of the outflow seen in the map of Ressler & Shure (1991). Hence, it is possible that the feature A delineates a disk around the protostellar object and the feature B may originate in the outflow.

3.2. GL2789

The map of GL2789 consists of 4 maser spots scattered mostly in the south-north direction. Assuming the kinematic distance to the source of about 6 kpc, the linear extent of the global structure will be 600 AU. The most intense feature B probably has a small scale structure similar to that of L1206. By analogy to L1206, one obtains $M/R^3 = (5 \pm 1) \times 10^{-7}$ $M_\odot AU^{-3}$. This value is also higher than that obtained by Minier et al. (2001). Assuming that the mass of the central object is 10 $M_\odot$, which is following from infrared luminosity (Minchin et al. 1991, and references therein), the disk radius will be about 280 AU. For the whole structure seen in Fig. 2, we obtained $M/R^3 = (2.6 \pm 0.3) \times 10^{-8}$ $M_\odot AU^{-3}$, the value being in agreement with Minier et al. (2001) data. It implies the disk radius of about 700 AU with the above mentioned mass of the central source.

4. Conclusions

Both masers were identified with protostars seen in the infrared. Brightness temperatures of the most intense features exceed 1.1×10^{10} K and 1.4×10^9 K for L1206 and GL2789 respectively. The L1206 feature A and probably GL2789 feature B are geometrically ordered structures with velocity gradients, which may represent edge-on disks. The size of such disk for the feature A of L1206 is estimated to be about 140 AU, and for GL2789 feature B to be about 280 AU. For the large scale GL2789 structure the estimated disk radius is about 700 AU. The feature A in L1206 is probably originated in the disk and the feature B may be connected with an outflow seen in the infrared.

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